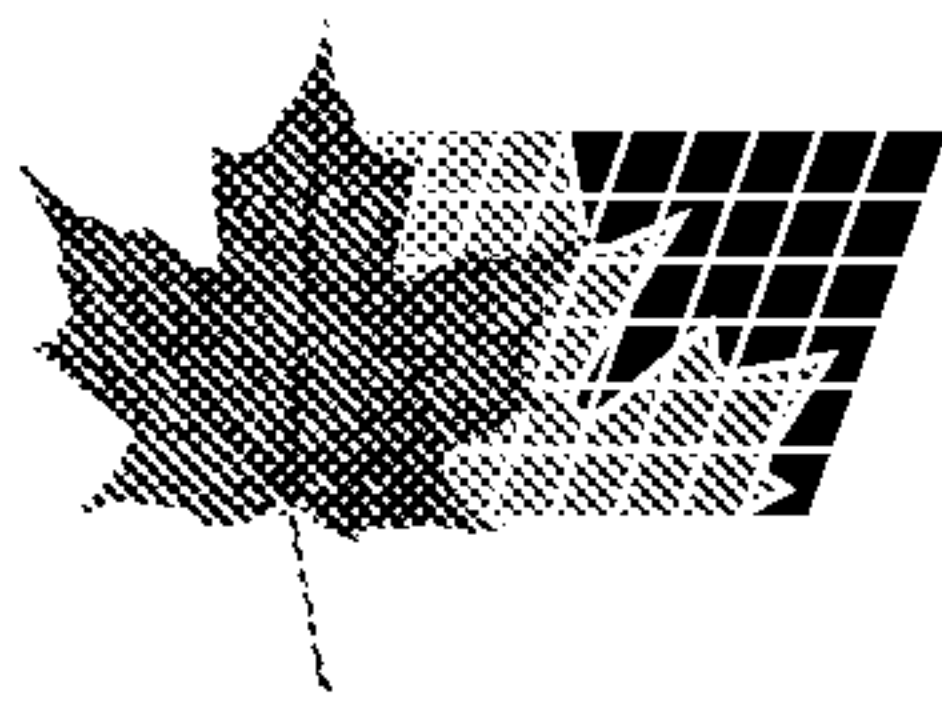




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(54) **APPAREIL POUR GUIDER ET MESURER LE MOUVEMENT DE
LA COLONNE CERVICALE, DE LA TÊTE ET DES ÉPAULES
ET POUR ÉVALUER LA POSTURE ET L'ÉQUILIBRE**

(54) **APPARATUS FOR GUIDING AND MEASURING THE MOTION
OF THE CERVICAL SPINE, HEAD AND SHOULDERS, AND
FOR ASSESSING POSTURE AND BALANCE**

**APPARATUS FOR GUIDING AND MEASURING THE MOTION OF THE
CERVICAL SPINE, HEAD AND SHOULDERS, AND FOR ASSESSING POSTURE
AND BALANCE**

Field of the Invention:

The invention relates to an apparatus for guiding and measuring the motion of the cervical spine, head and shoulders, and for assessing posture and balance.

Background of the Invention:

The type and extent of cervical spine injury sustained in an automobile accident can vary from common whiplash to more serious fractures, dislocations or death. Spitzer et al., (1995) reported that 20% of all claimants to the SAAQ (the universal insurance coverage society in Quebec, Canada) are diagnosed as having whiplash-associated disorders (WAD). This group was responsible in 1987 for nearly 50% of all compensation-related costs (\$9 M of a total of \$18 M).

Chronic pain syndrome (CPS) is frequent in patients diagnosed with WAD (12.5% are still compensated after 6 months) and involves significant costs to the SAAQ (46% of the total compensation distributed by the SAAQ in 1987). Thus, the main financial burden due to patients with WAD results from a small percentage of recipients who become chronically afflicted. Most patients with WAD-related CPS exhibit no objective physical finding permitting the identification of pathology, and often cases are eventually investigated for a possible psychiatric or psychological etiology (Rosomoff et al., 1989, Spitzer et al., 1995).

Jónsson et al., (1991) presented compelling data supporting an organic basis for the condition observed in patients with WAD-related CPS. Studying fresh cadaver

cervical spines (all of them obtained from victims of traffic accidents), they discovered several pathological lesions believed to be capable of producing pain, such as injuries to the discs, ligaments and the cervical zygapophyseal joints. None of these anomalies were detectable on plain radiograms, whereas other radiologically-detected anomalies proved to be false positives upon comparison with forensic examinations. Jónsson et al. concluded that a negative radiogram does not necessarily indicate the absence of soft tissue injury. The findings question the clinical usefulness of conventional radiography for the detection of cervical spine injuries, except for suspected major traumas such as fractures.

The most frequently used radiological diagnostic tools for assessing disability and loss of function of the spine are magnetic resonance imaging (MRI) and computed tomography (CT). MRI and CT are useful when diagnosing lateral canal entrapment, degenerated disc, and spinal stenosis, and to differentiate between a contiguous disc herniation and one that is sequestered or extruded. However, studies using MRI and CT have shown abnormalities in a significant proportion of asymptomatic individuals (Wiesel et al., 1984, Weinreb et al., 1989; Boden et al., 1990 Jensen et al., 1994; Boos et al., 1995).

Since WAD may produce abnormal motion of the cervical spine, it has been proposed that "functional" radiograms would detect the unstable or hypermobile spine segment when in motion. Dvorak et al., (1988) used a technique, first described by Penning (1960), to investigate the segmental mobility of the cervical spine of normal subjects. Patients were asked to actively execute a full flexion and full extension of the cranio-cervical complex. At the end-range of each movement, a plain anterior-posterior radiograph was taken and the difference in vertebral position noted. From the flexion position, the locus of the instantaneous axis of rotation of two consecutive segments was calculated together with the corresponding degree of rotation.

The basic movements of interest for appreciating cervical pathology are flexion and extension in the sagittal plane, lateral bending in the transverse plane and axial rotation in the coronal plane (Figure 1).

Although fast and practical for routine clinical practice, the above technique depends upon patient collaboration that may be impaired due to pain or fear of pain. This pain may deform the patterns of movement and render the detection of hypermobility or instability difficult. Both hypermobility and instability are believed to be the result of soft tissue injuries. Hence, Dvorak et al., (1993) examined the problem further, and suggested using passive motion of the cervical spine for segmental mobility measurements on three groups of patients diagnosed with radicular disease, degenerative disease, and WAD. During sagittal flexion/extension, they compared cervical spine mobility with that of normal subjects. Significant hypomobility at the C6-7 level was reported for both the radicular and the degenerative group, but only a trend towards hypermobility of the upper segments in patients with WAD. Dvorak et al., (1993) therefore concluded that: 1) the prevalence of hypomobility in the patient groups as a whole suggested that either a limiting mechanism was activated, or a reflexogenic muscular restraint caused by pain, or a purely mechanical restraint (deformation of the facets, reduced intervertebral disc space, etc.) were the basis for these observations; 2) muscular restraint operates as a limiting mechanism in the WAD group of patients; 3) the important factor in determining instability is not the quantity of movement but the quality of that movement.

Conventional imaging methods are not well-suited to describing coordination between cervical spine segments and the musculo-ligamentous structures linking them to the skull and the shoulder girdle. Therefore, to investigate the quality of motion requires a different set of tools.

Several devices are attempting to determine the presence or absence of cervical pathology by monitoring the relative motion of the head with respect to the shoulders. All methods rely on tracking the motion of markers placed on the head and/or the shoulders. These markers can be either active or passive.

Ultrasonic active markers. The equipment manufactured by Zebris, a German company, illustrates this method. The marker emits an ultrasonic pulse (around 40Khz or so) that is captured by three or more microphones

appropriately placed in the vicinity. A computer measures the time it takes for the pulse to travel from the marker to each microphone. These times are converted into distances and by triangulation, the position of the marker is reconstituted in space. Ultrasonic markers cannot operate too far (2 meters or so) from the microphones since the velocity of the sound is relatively low.

Active optical markers. The marker emits a flash of light (infrared) which is captured by appropriate cameras (Optotrak, Northern Digital, Waterloo, Canada, or Flashpoint, IGT, Boulder Colorado, USA). The coordinates of the marker are reconstructed by direct linear transformation from the information provided by each camera. The distance from the marker to the camera must be less than 15 meters.

Passive optical markers. The marker reflects the light it receives from a light source (tungsten or infrared). The reflected light is collected by high-resolution television camera. A computer then generates the coordinates of the markers. This method is used by Ariel, Motion Analysis, Peak performance technology, Polaris, Elite, etc. The distance from the markers to the camera is also of the order of 15-20 meters.

Passive electromagnetic markers. A fixed transmitter broadcasts an electromagnetic field in a given volume (a few feet in diameter). The marker is an antenna generating a signal from the electromagnetic field. The signal is converted into a six degrees of freedom information vector, giving the position and orientation of the marker in space. Ascension Technologies and Ptolemus manufacture these devices. The distance from the marker to the electromagnetic source is about 3-4 meters.

Kinex IHA (Phoenix, Arizona) uses passive electromagnetic markers to measure the relative motion of the head with respect to the shoulders (US patent # 5,203,346). Spinex (Montreal, Canada) uses an active optical marker to measure the relative motion of the head with respect to the shoulders and the motion of the cervical spine (US patent #4,655,227; 4,664,130; 4,699,156; 4,971,069

Canadian patent #1220273; 1220272; 1219673; 1297952; European patent # EP 0310901 B1.

5 The purpose of capturing the kinematics of the markers is to extract clinical information on the status of the cervical spine of the subject. To simplify the pattern recognition of potential pathologies, the motion of the head is restricted to movements in the sagittal, frontal and transverse planes. In general, the subject is shown how to move his/her head. The problem is that the subject may or may not properly move his head in the desired plane without either coaching
10 from the technician administering the test, or some form of feedback.

Kinex IHA provides a visual feedback by attaching a laser pointer to the subject's head and placing a grid of fixed reference lines in front of the patient. The subject must aim the red dot of the laser pointer's light beam on the reference lines,
15 thereby restricting the head to follow a desired trajectory.

Aiming a dot at a specific reference location on a wall does not define the full orientation of the head in space. The subject cannot appreciate the head motion in the coronal plane. Movement of the head in the coronal plane contains
20 important information about the condition of the facets of the cervical spine. The Kinex apparatus cannot guide the head motion in the coronal plane.

Clinically, it is very important to control the motion of the head in the sagittal, transverse and coronal planes. To guide the motion of the head in the desired
25 three planes, one must introduce an artificial horizon line in the field of view of the subject. It is by controlling the artificial horizon that the subject will control the coronal plane motion.

30 **Summary of the invention**

The object of the present invention is to provide an apparatus for use to fully control the motion of the head in three planes. This is achieved by harnessing the

subject as described in European patent: EP 0310901 B1, in which the described headgear is replaced by a Head Display System (HDS) similar to those used in flight simulation or computer games. The displayed image contains all the data needed to control the head in three planes, including the critical artificial horizon.

5 As the HDS is attached to the head, any head motion will result in a change in the artificial horizon seen by the subject. This provides the subject with the information needed to correct his head movement. The HDS comprises two high contrast, full color, liquid crystal displays, 3D head-tracking devices (using any type of markers placed on the HDS) with stereo earphones . Many manufacturers

10 of HDS are on the market, such as Kaiser Electro-Optics (www.keo.com).

Description of the drawings

15 Fig. 1 is a schematic representation of the basic movements of the cervical spine;

Fig. 2 is a schematic representation of a prior art method for providing feedback to a subject and guiding the head movement;

20 Fig. 3 is a schematic representation of the head-mounted laser for use in the prior art method of Fig. 2;

Fig. 4 is a front view of the grid for use in the prior art method of Fig. 2;

25 Fig. 5 is a schematic representation of a head display system (HDS) according to the invention;

Fig. 6 is a representation of the placement of the HDS on a subject;

30 Fig. 7 is a schematic representation of the image a subject sees before testing begins;

Fig. 8 is a schematic representation of the image a subject sees when tilting the head to the right;

Fig. 9 is a schematic representation of the image a subject sees during a lateral bending test;

Fig. 10 is a schematic representation of the image a subject sees when sweeping from left to right;

Fig. 11 is a schematic representation of axial rotation without lateral bend;

Fig. 12 is a schematic representation of head flexion without lateral bend;

Fig. 13 is a schematic representation of diagonal head tracking without lateral bend;

Fig. 14 is a schematic representation of circular head tracking without lateral bend;

Figs. 15a and 15b are a schematic representation of horizontal translation of the head;

Fig. 16a is a schematic representation of the form angles for determining the position of an arm; and

Fig. 16b is a schematic representation of the placement of the markers for determining the position of an arm.

DETAILED DESCRIPTION OF THE INVENTION

The first step is to harness the subject with the cervical markers. This procedure has been described previously (Roosman et al., 1993). Briefly, a series of 9

active optical markers (infrared light-emitting diodes) are placed on the skin over the cervical midline from the base of the skull (around C2-3) to the mid-thoracic spine, another 2 markers are placed on the shoulders blades, and 2 more on the iliac crests (Figure 6). Three markers are placed in a triangular manner (to allow planar displacement measurements) on the HDS attached to the head. Head and shoulder motion could also be monitored with electromagnetic sensors.

The test begins by familiarizing the subject with controlling the movement of the head as guided by the HDS. Figure 7 represents what the subject sees at the beginning of the test. The subject sees a cross (marker) representing his head orientation in the sagittal and coronal planes and the artificial horizon representing the coronal plane. He also sees the sky above the horizon. When the head is correctly aligned, the movable cross, representing the head's desired orientation, is in the center of the screen.

The computer then instructs the subject (voice through the earphones) to move his head sideways and relate the tilt in the transverse plane to the tilt of the artificial horizon (Figure 8). In so doing, he learns to appreciate head lateral bending with the artificial horizon motion.

The subject is then instructed to focus on a cross (marker), then move his head sideways thereby bending his cervical spine laterally (motion in the coronal plane) without any sagittal or axial rotation (Figure 9). This is a pure lateral-bending test. The cross must be kept fixed while the subject tilts his head.

To test the axial rotation of the cervical spine, the subject is then instructed to track a movable black cross ("B"), travelling horizontally across the field of view, without tilting the artificial horizon (Figure 10). The computer measures what the subject actually does and displays immediately any necessary correction by changing the artificial horizon or the position of the crosses displayed. The desired head motion is a sweep from left to right while the artificial horizon is maintained steady. This tests the axial rotation of the cervical spine.

For instance, when asked to move his head to position "B" the subject may tilt his head and produce an unwanted motion in the coronal plane. When this occurs the artificial horizon will tilt by the same amount the head has rotated in the transverse plane, thereby giving the subject immediate feedback permitting him to correct his head motion to the desired trajectory. An error zone is displayed, and as long as the horizon remains within the error zone while cross "A" follows cross "B", then the head is properly positioned for the measurement to have clinical significance (Figure 11). In practice, it is difficult to maintain a steady artificial horizon, and hence a small error is tolerated. The acceptable error zone is shaded.

To test the sagittal plane motion of the cervical spine, the subject is instructed flex and extend his spine (nod head forward then move head back up again) without any lateral bending, by following the movement of marker "B" (Figure 12). The subject is asked to flex and extend his cervical spine without any lateral bending. Since this is difficult to do, the acceptable lateral bending error is shaded.

To test a combination of sagittal and axial motions the subject is instructed to follow the movement of marker "B" without any lateral bending (Figure 13). This test combines flexion and axial rotation while attempting to minimize lateral bending.

More complex motion can be requested so that the subject loads the different structures of his cervical spine. The subject is instructed to move his head so that cross "A", which he controls by moving his head in the sagittal and coronal planes, tracks a computer generated target (cross "B") moving in predetermined trajectories. (Figure 14).

The upper cervical spine can be tested by horizontal translation of the head (Figure 15 a-b). In Figure 15a, the subject retracts his head by a pure translation. In Figure 15b, the subject advances his head by a pure translation.

To visualize these translations, a sphere or a circle appears closer or further from the head when the subject protrudes or retracts the head. The importance of such translation movements has been described in the literature (Grauer et al., 1997).

5

The purpose of having the subject's head move in specific patterns is to exercise specific structures of the cervical spine, and measure the function of the subject's cervical spine. A detected functional anomaly for a specific arc of motion can then be associated with a specific structural element, the identification of which is the desired objective of the diagnosis.

10

Data Processing

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The data are compared with that of a normative database, and the distance between the subject and the normal is determined according to the method described by Gracovetsky et al., (1995) and Newman et al., (1996). There are three objectives:

20

Estimate the distance between movements of the normal and those of the subject;

25

Propose an index of functionality for motion in the sagittal, transverse and coronal planes with and without loads held in the hands or attached to the head;

Identify which damaged structure is most likely to explain the observed movements.

30

Further application: The Shoulder Joint

The ability to provide feedback to the subject during testing is quite important. When testing the shoulder joint, the subject moves his arm as requested by the clinician.

5 The diagnosis is made from these observations. Quantification is however difficult.

10 It is proposed to use the same methodology, either a HDS or a display system located in front of the subject. By placing electromagnetic sensors on the skin along the spine arm and forearm, it is possible to track the motion of these structures with respect to the shoulder. When the position of the trunk is recorded using skin markers, the position of the arm with respect to the trunk can be established. The combined motion of the arm, forearm and shoulder is displayed in front of the subject in the form of a cross that moves when the subject moves his arm. The subject first learns to relate the motion of a movable cross to the motion of the arm (see Figure 16a) which shows the four basic angles for determining the position of the arm captured by the sensors.

20 The objective is to guide the subject to move his arm and forearm in specific trajectories that elicit various anatomical structures. For instance, testing of the functional integrity of the rotator cuff of the shoulder is a major clinical problem particularly with regard to return-to-work decisions after injury or reconstructive surgery. While many individuals accommodate well to a rotator cuff tear, others may have a very significant disability. Magnetic resonance imaging of the rotator cuff does not give a good indication of the functional capacity, and the proposed device is intended to quantify these functional losses. The rotator cuff acts to stabilize the humeral head in the glenoid, such that the lever arm of the deltoid muscle is preserved so as to enable forceful movements. Thus the rotator cuff is stressed maximally during abduction and flexion movements of the shoulder, particularly when the humerus is close to 90 degrees in relation to the trunk with the elbow in extension (thus creating the longest lever arm). We propose to test the rotator cuff by asking the standing subject to perform a forward elevation of the upper limb, with the forearm in supination and extension, to 180 degrees (or maximum elevation), followed by descent to a neutral posture. Markers on the scapula, thorax, spine

(Figure 15b), arm and forearm will permit tracking of the coordination and give feedback to the subject so that the movement is completed as requested (within the physical limitations of the subject). Deficient function of the rotator cuff is manifested by abnormal scapulo-thoracic and gleno-humeral coordination, particularly as the subject reaches 90 degrees of elevation, ascending and descending. Further testing with loads will confirm the diagnosis of dysfunction. Additional movements tested include:

Internal rotation of the shoulder to enable the subject to place his thumb along the dorsal spine as high as possible (normally to T8);

External rotation and abduction of the shoulder in the frontal plane to enable the subject to place his hand behind his head;

Forward flexion of the shoulder to 90 degrees associated with maximum internal rotation, followed by adduction of the shoulder.

These additional movements will demonstrate additional function of the shoulder with particular regard to the integrity of the capsule, external rotation function of the shoulder and impingement syndrome of the rotator cuff as it passes under the acromion.

The subject will have immediate feedback on whether his shoulder is properly tested because he will see a representation of his arm motion, and maintain a visual clue at specific positions on a computer screen (projected on a wall, or using an HDS). The device will assess functional losses and provide an index of disability based on the actual and derived motion.

Other types of pathology could be investigated in a similar way.

Further application: Equilibrium of the elderly

Hip fractures in the population over 65 years of age are increasing in an exponential fashion. One of the major causes of these fractures is the decrease in the efficiency of the normal mechanisms of equilibrium in the elderly, resulting in increased susceptibility to falls. Osteoporosis, of course is another major factor, particularly in women. Identification of individuals at particularly high risk for falling is part of the strategy for prevention. We propose a simple method of testing the equilibrium of the subject using the HDS incorporating controlled modification of the horizon. Identification of the subject's reliance on visual versus vestibular clues for the maintenance of equilibrium will suggest strategies for improvement (walker, cane, eyewear, providing useful information for modification of floor versus wall coverings or lighting to accentuate the horizon or decrease visual confusion). This methodology could be used to not only test the subject but also to improve equilibrium.

Subjects with impaired vestibular sensors can be expected to compensate their disability by excessive reliance on visual clues. By altering the visual environment, especially the horizon, the subject will get conflicting information between his/her eyes and ears. Such conflicting information may result in loss of equilibrium. The ability to introduce "controlled confusion" will permit a better appreciation of the vestibular deficiencies.

There are many devices intended to probe the ability of a subject to maintain equilibrium. In general, they consist in placing the standing subject inside a small cubicle without any visual reference. The subject stands on a platform that can be tilted. This supplies vestibular information that the subject must compensate for without visual clues.

The proposed device also incorporates a movable platform to provide direct vestibular input. By providing visual clues opposing the vestibular input, the subject will experience maximum sensory confusion. This will enable the Romberg and

Unterberger/Fukuda equilibrium tests to be performed. For example, see Zebris Germany.

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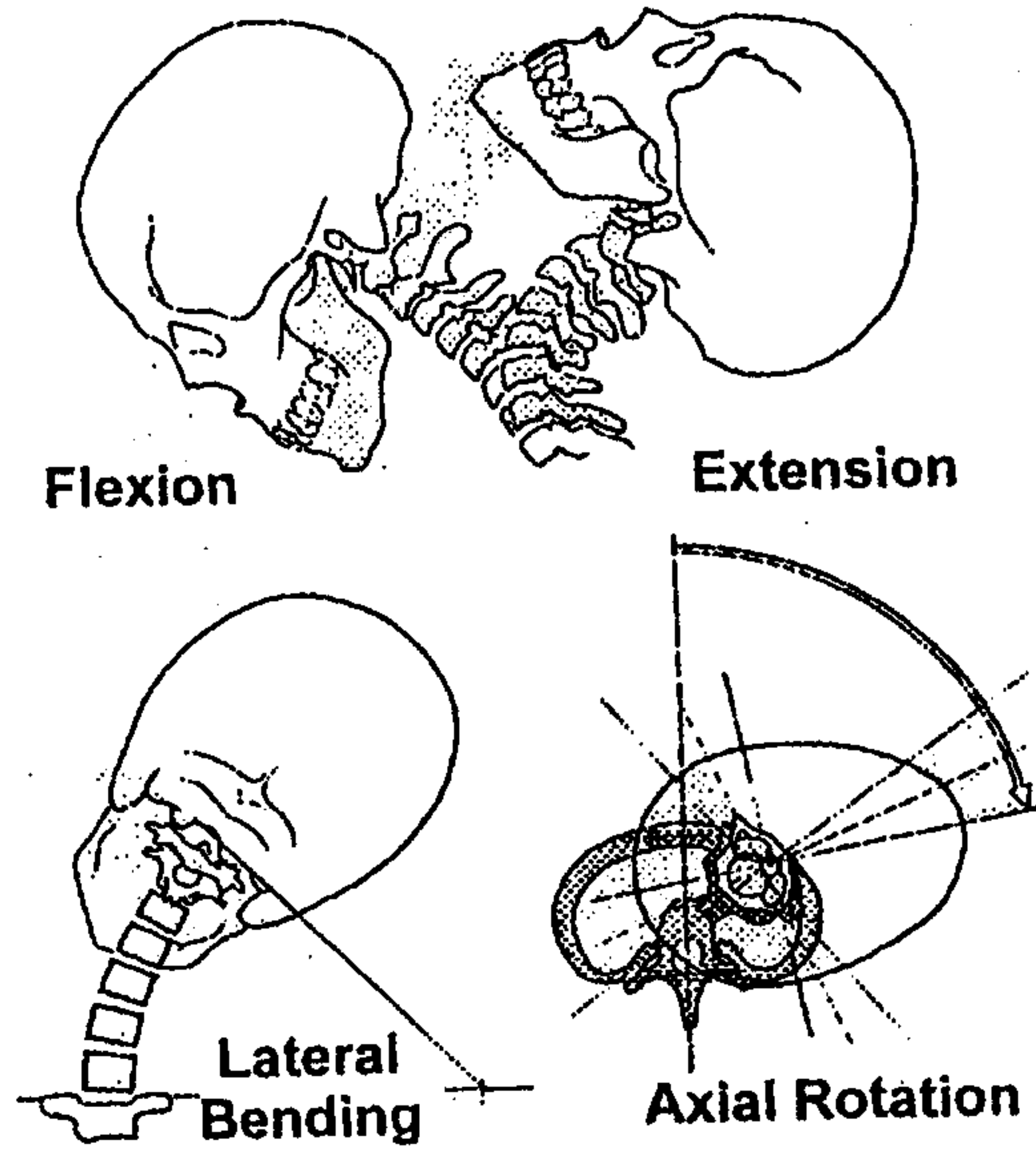


Fig. 1

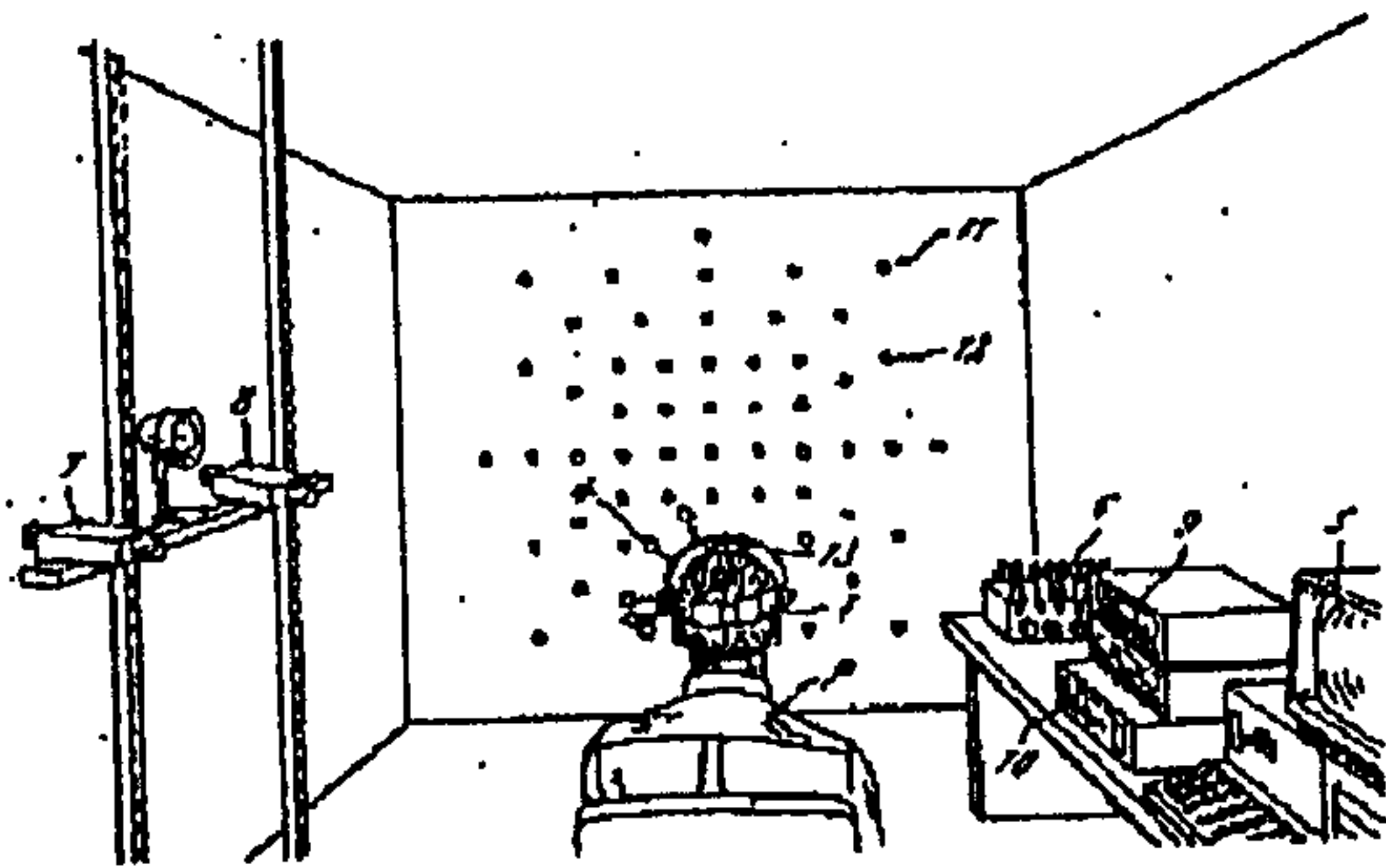


Fig. 2
(Prior Art)

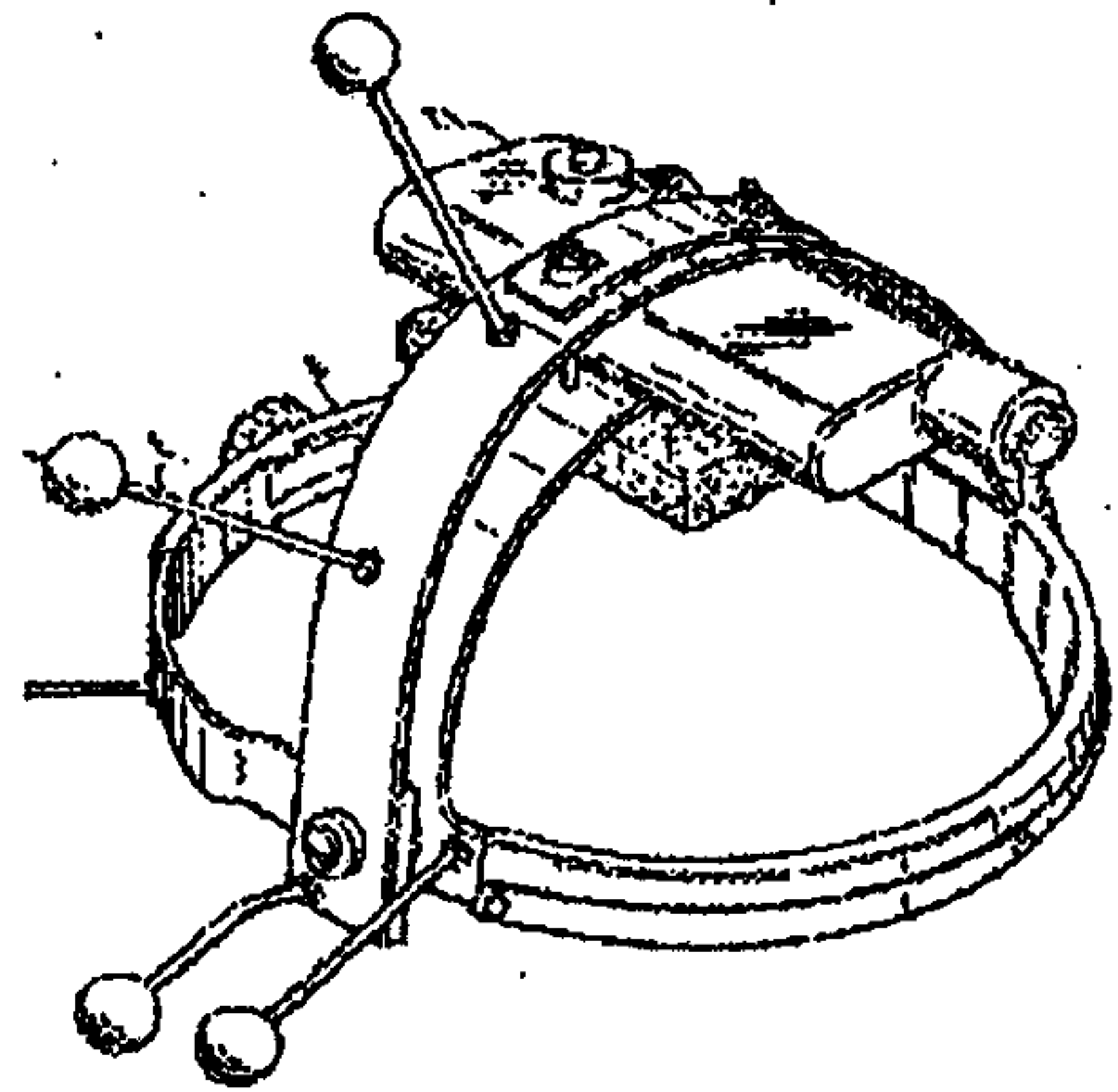


Fig. 3.
(Prior Art)

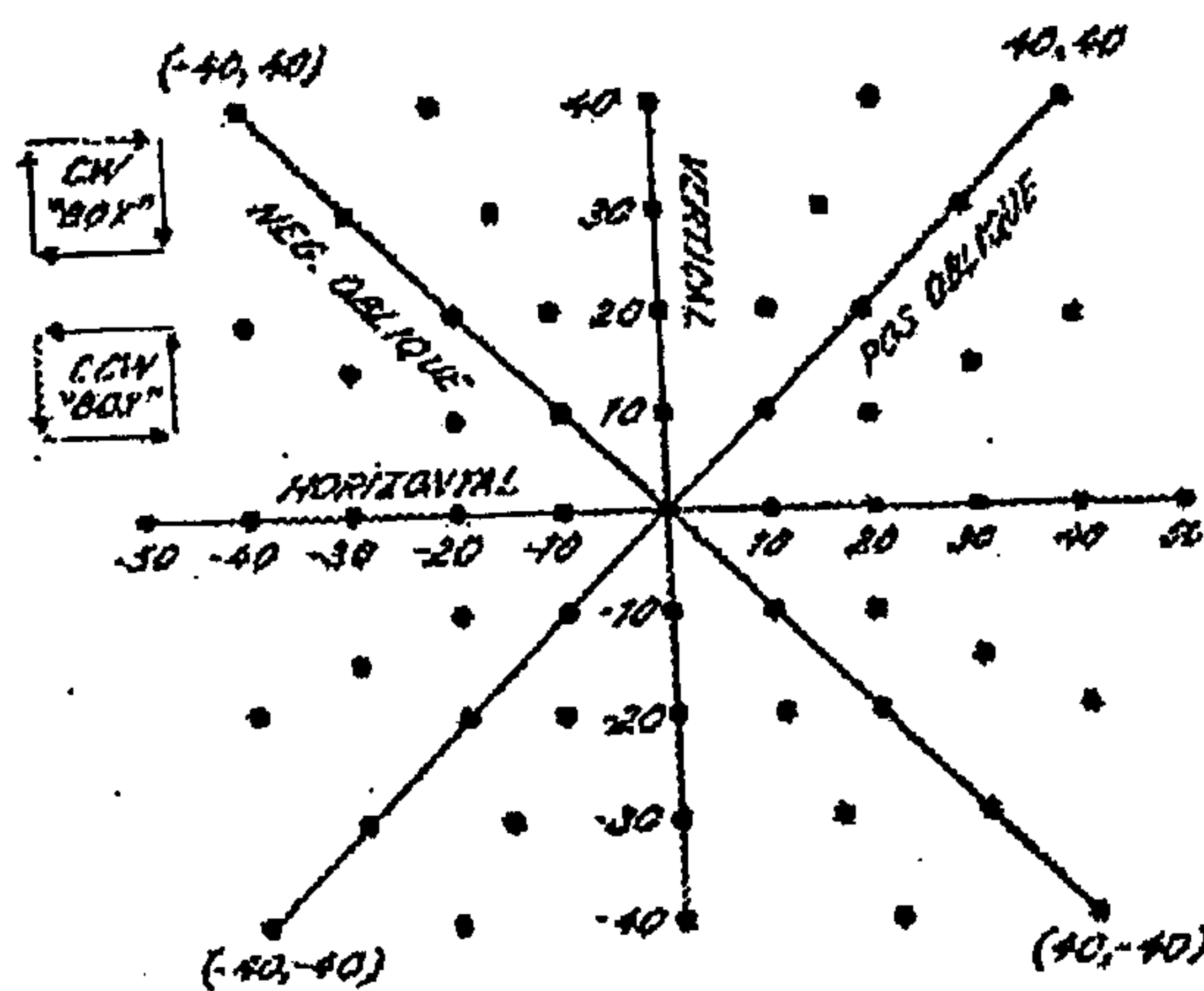


Fig. 4
(Prior Art)



Fig. 5

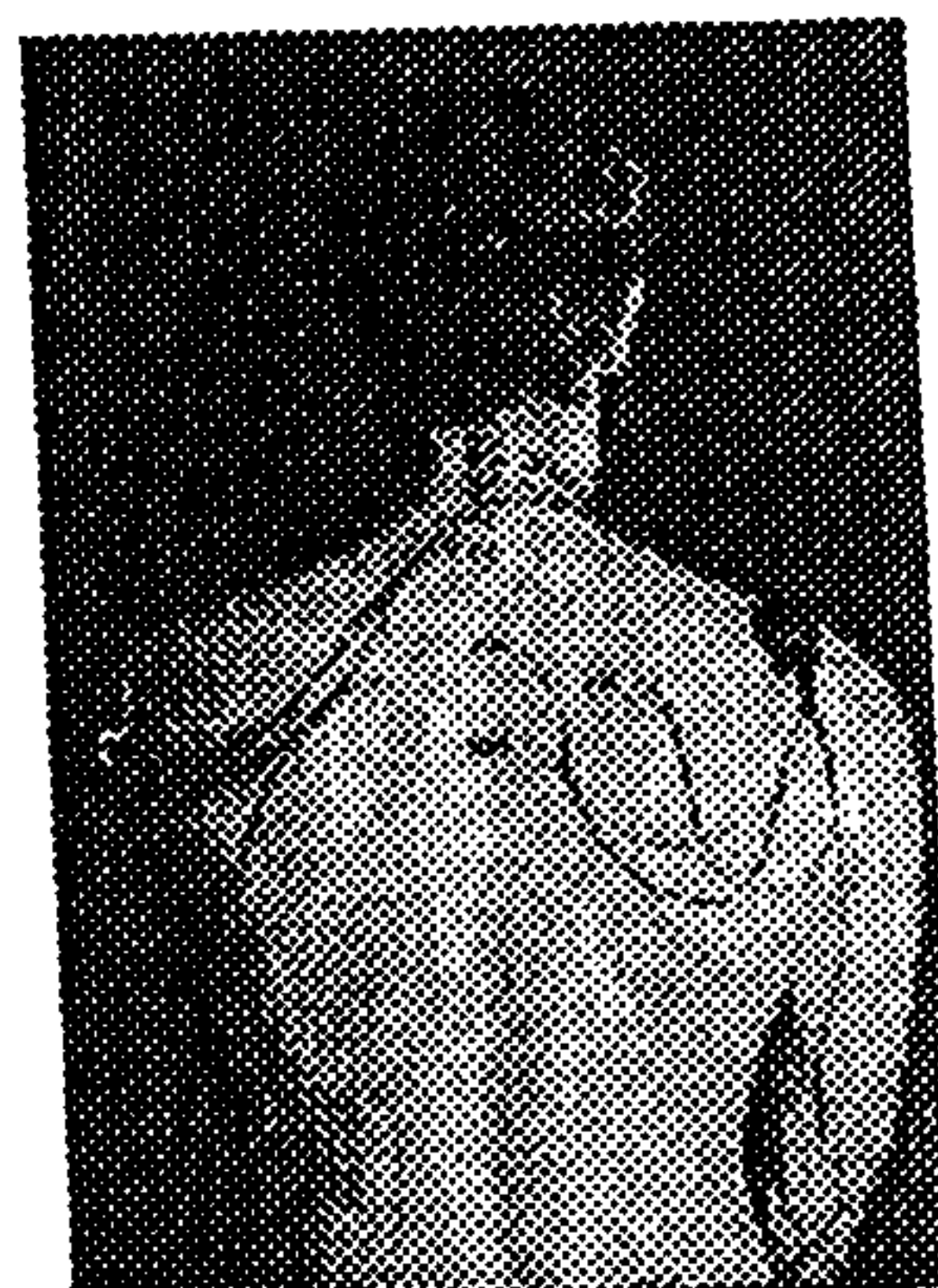


Fig. 6

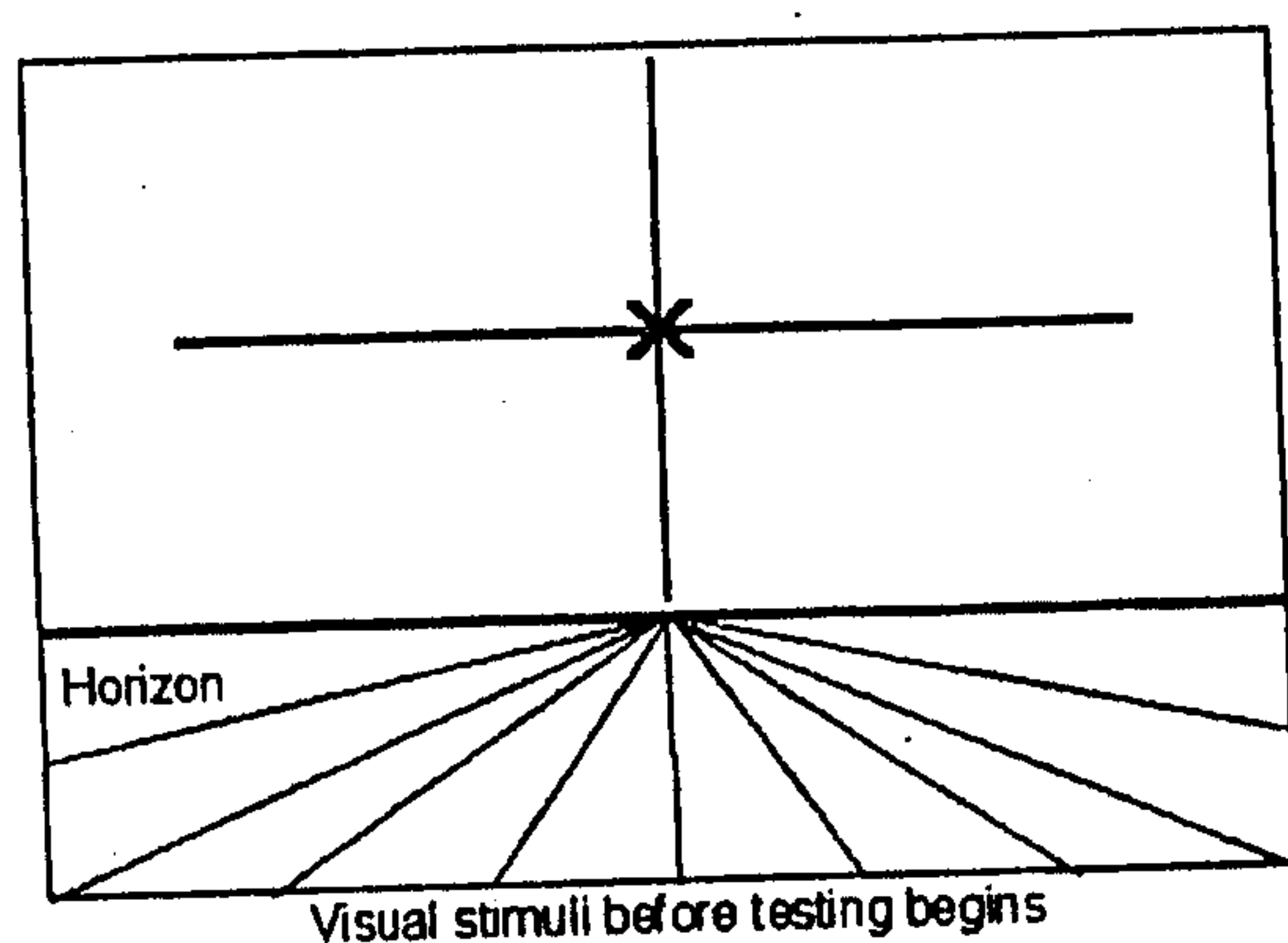


Fig. 7

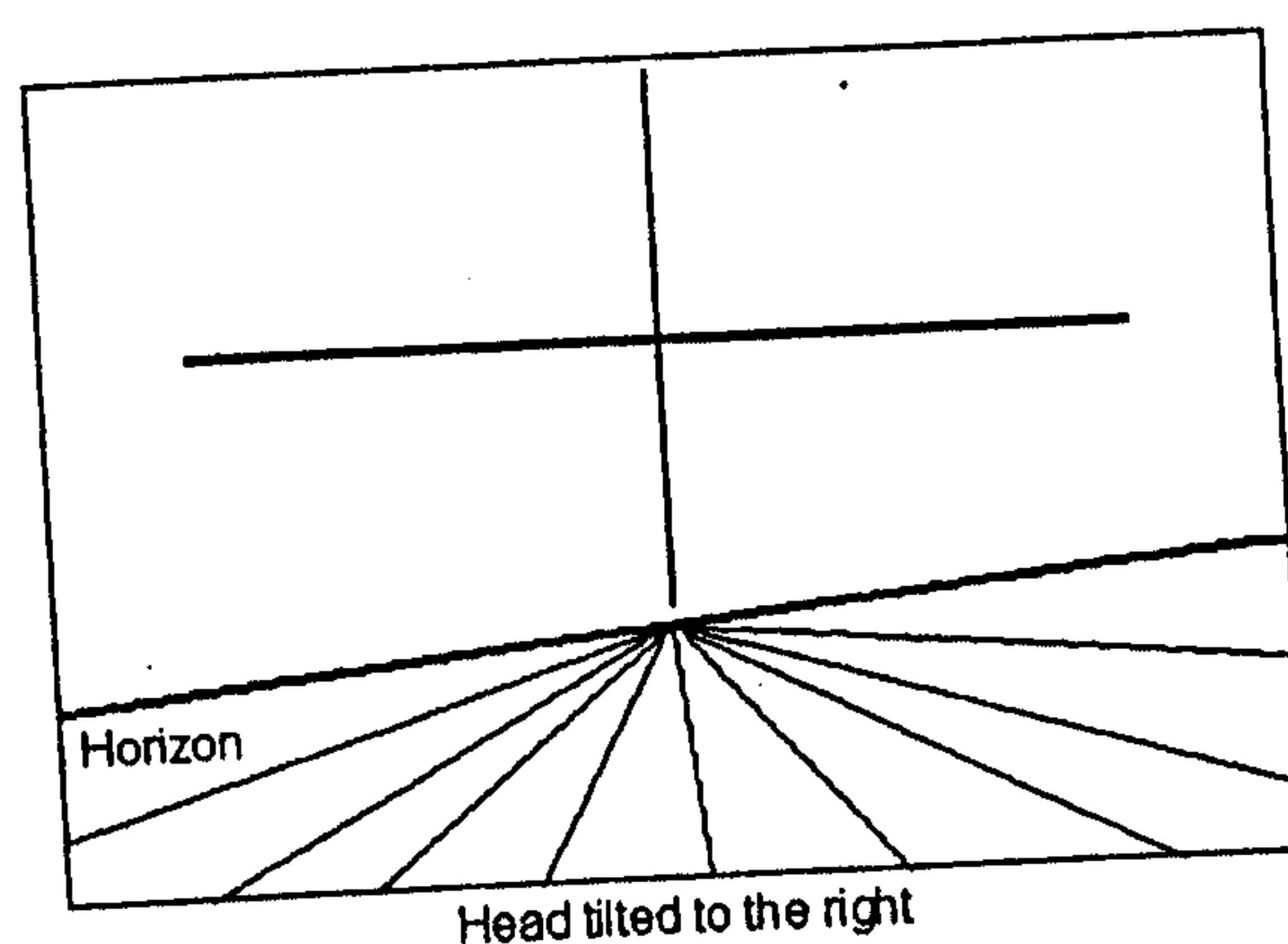


Fig. 8

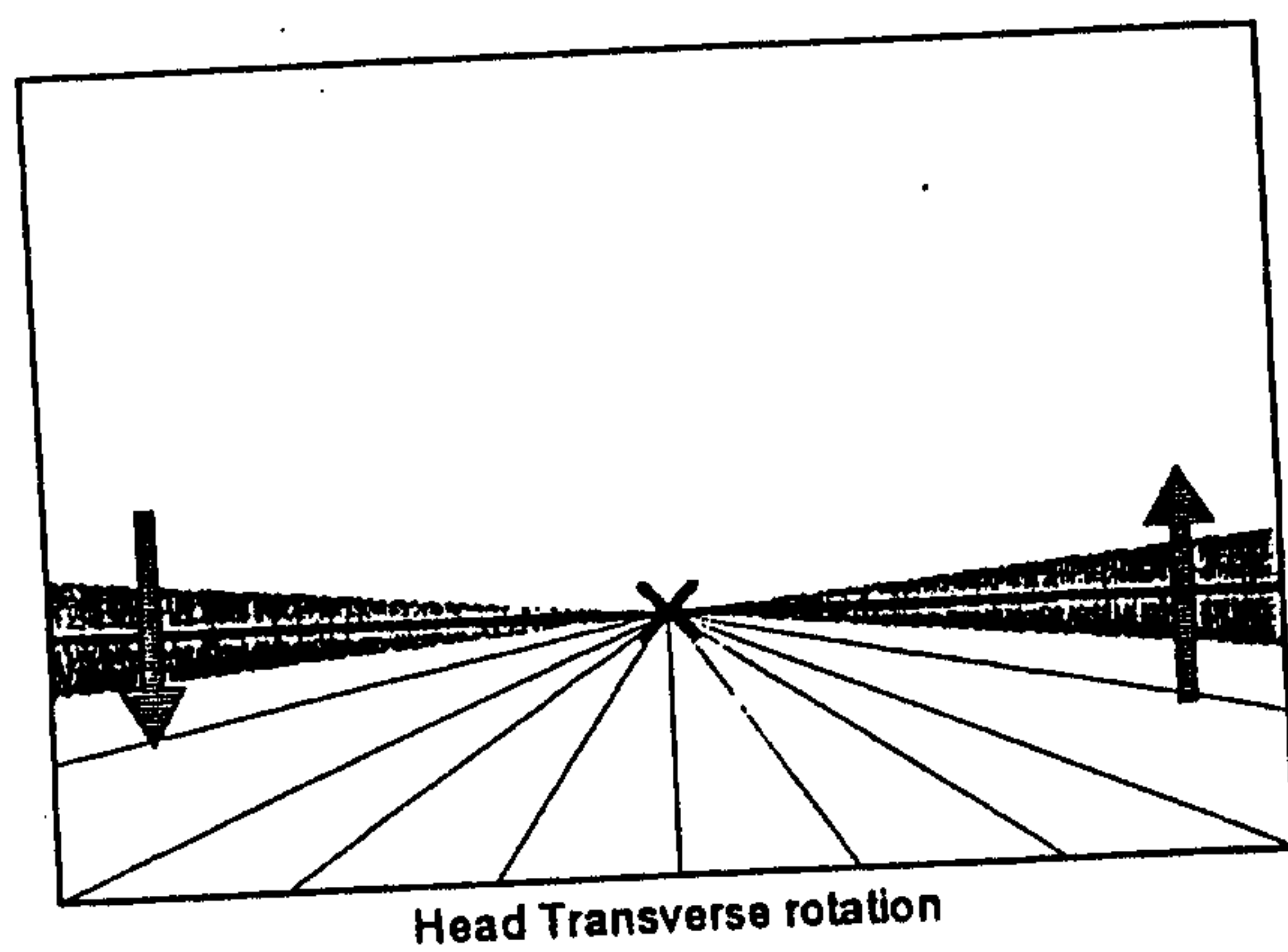


Fig. 9

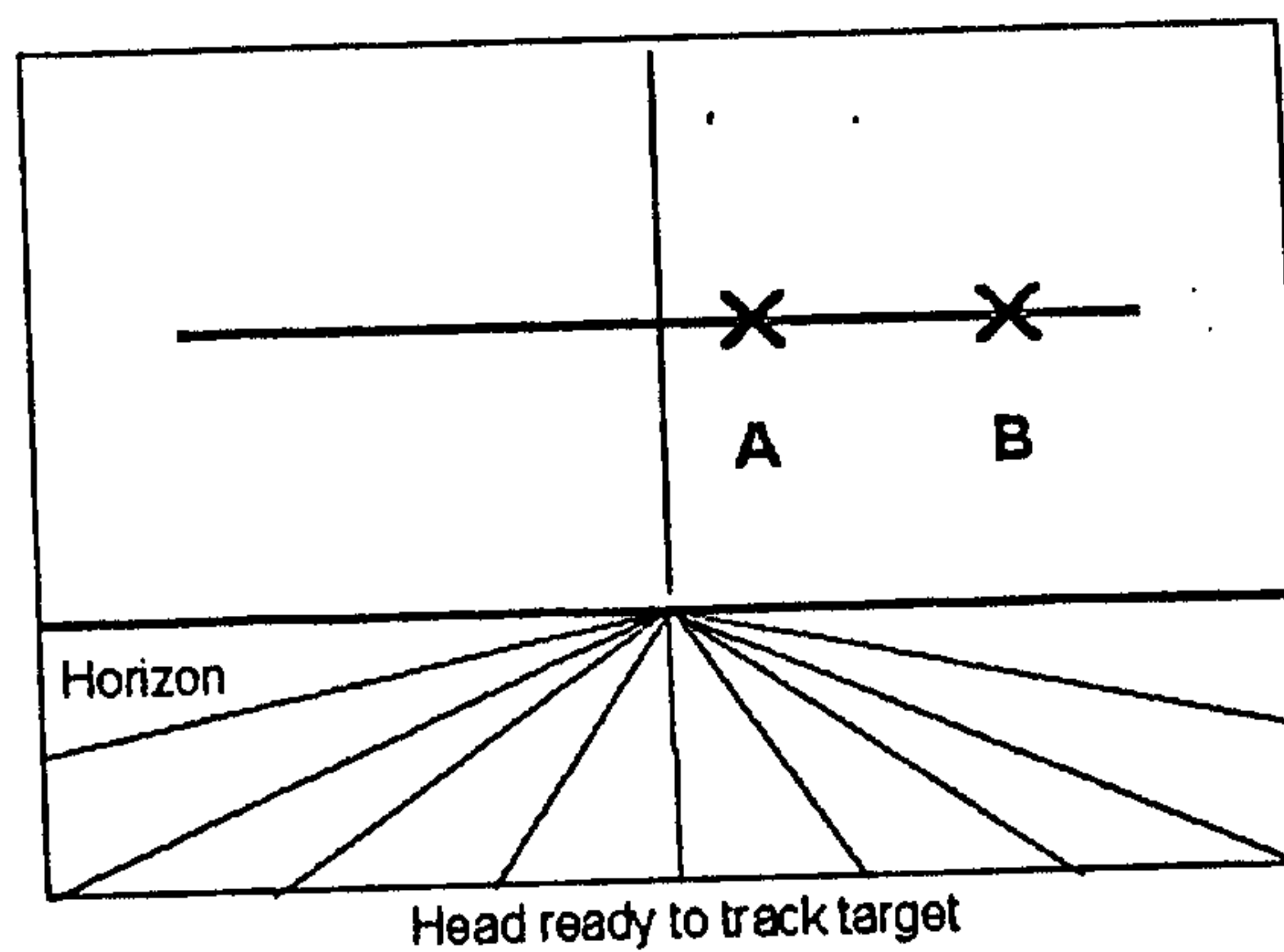
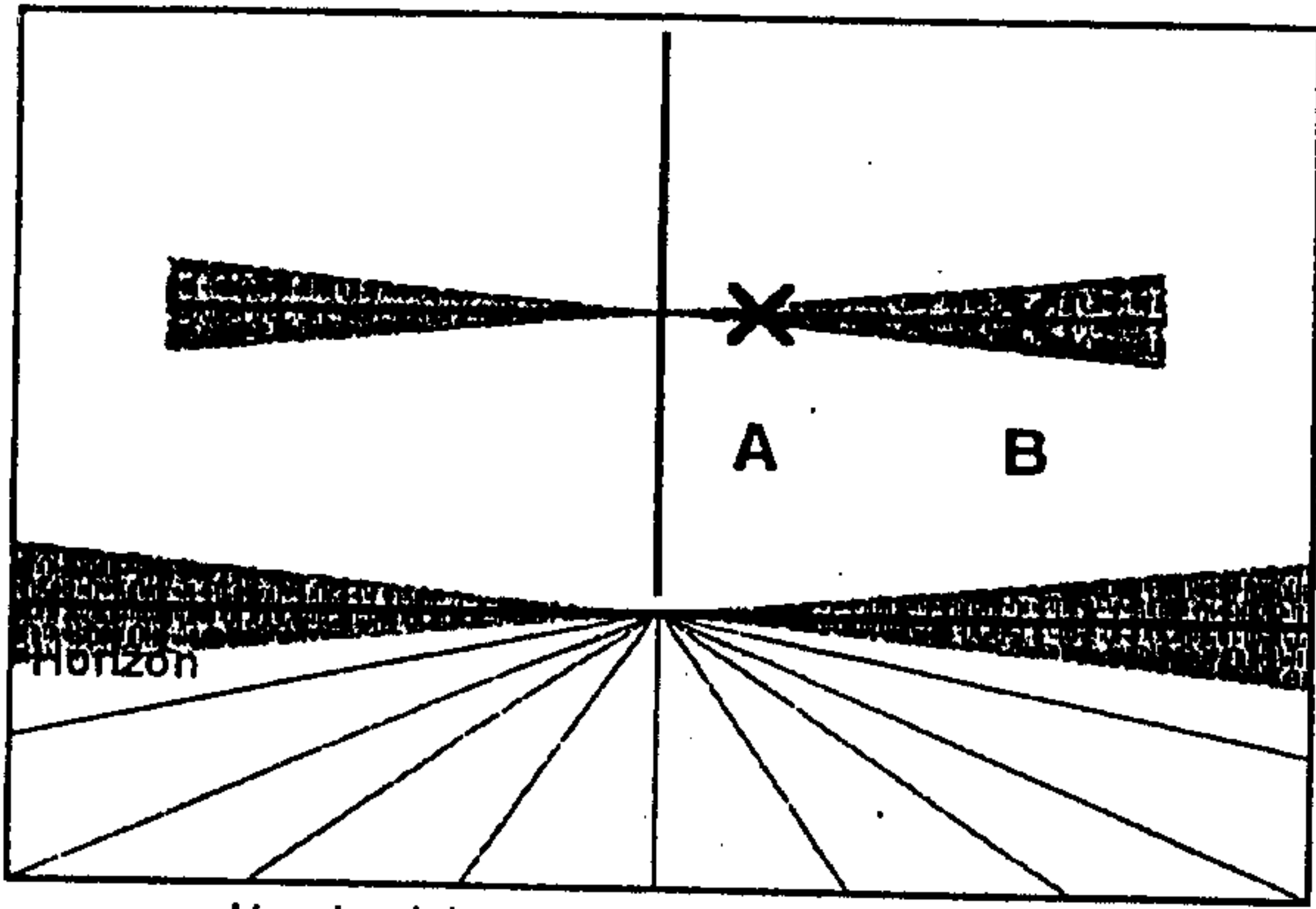
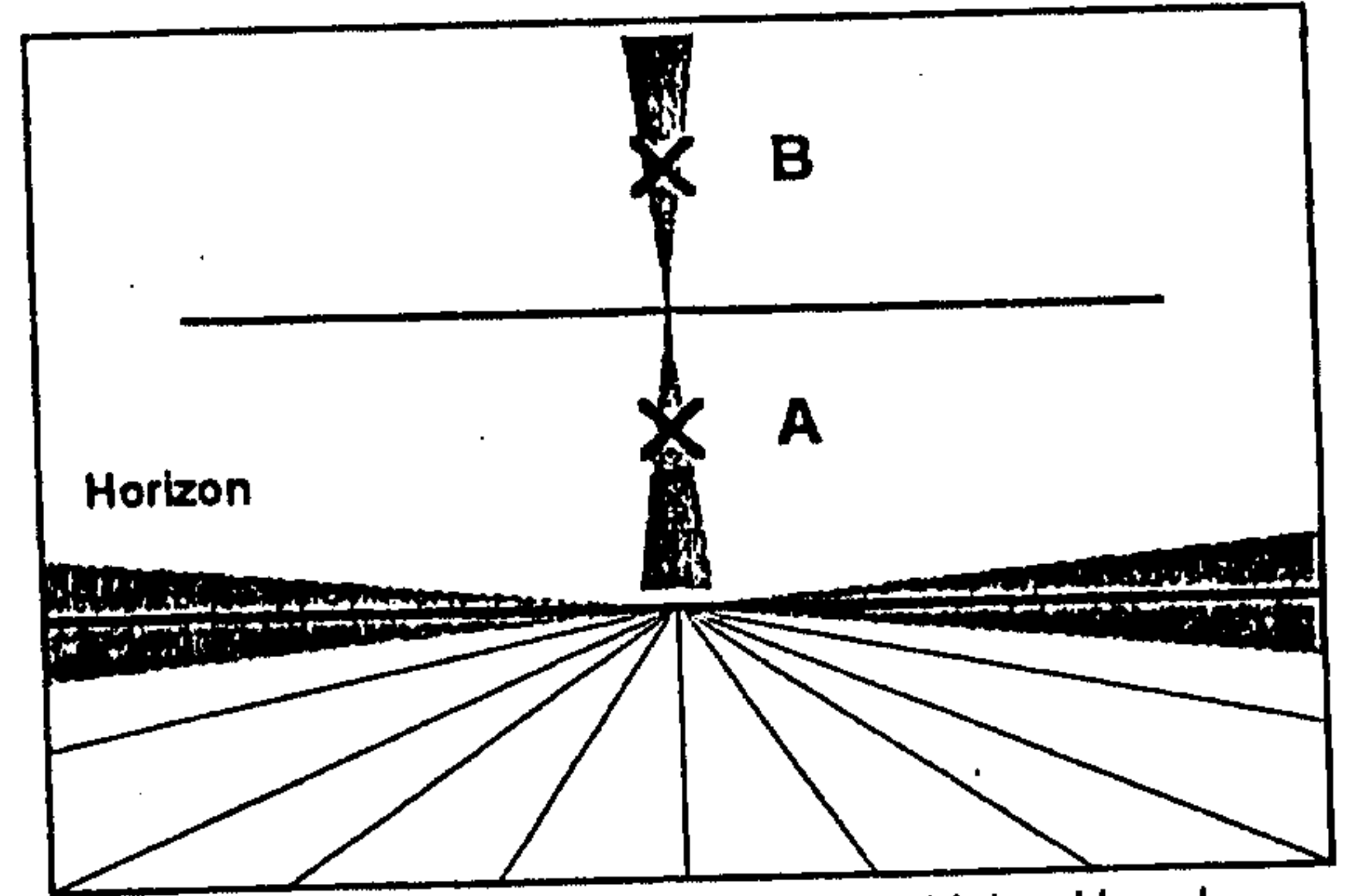


Fig. 10



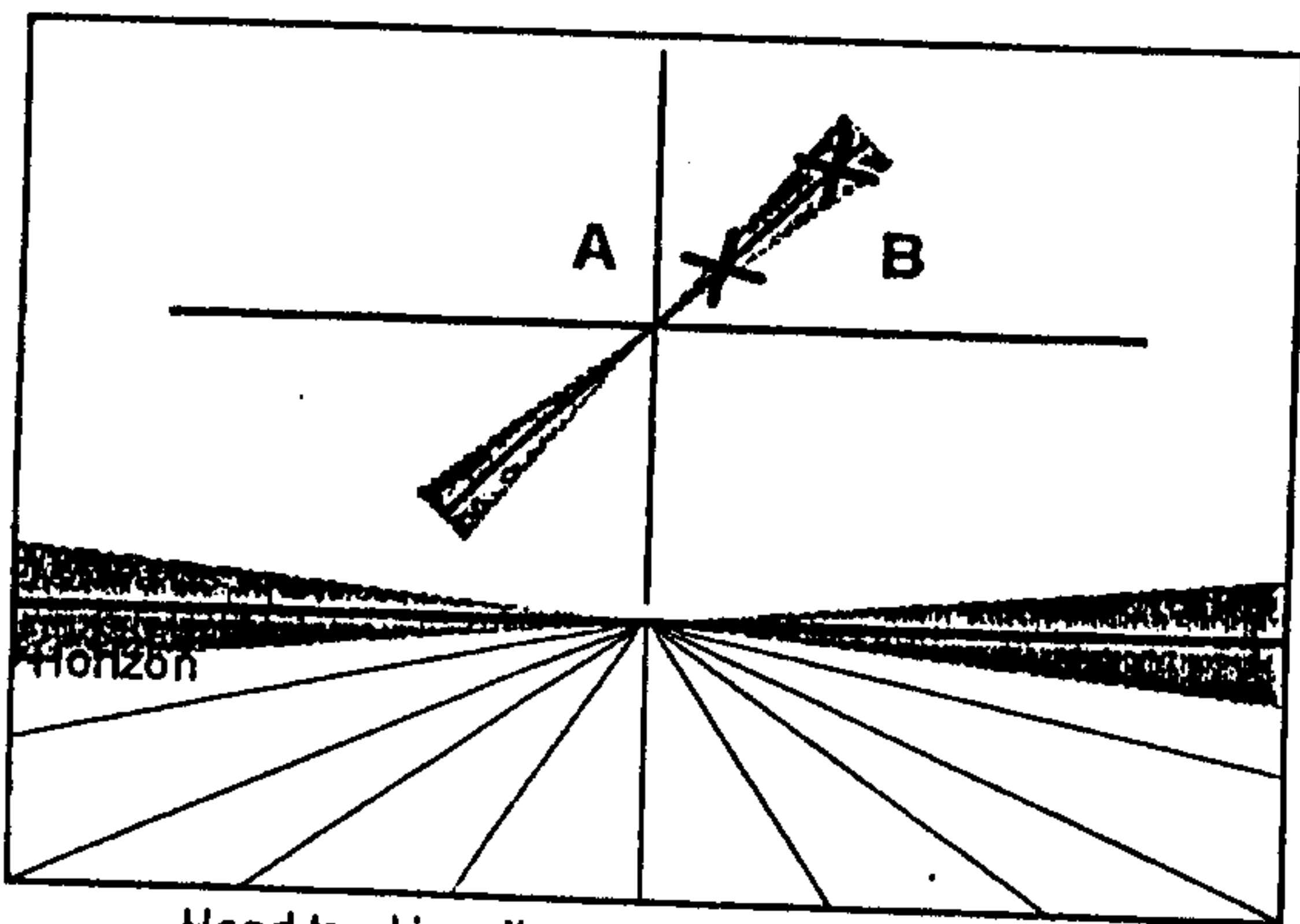
Head axial rotation without lateral bend

Fig. 11



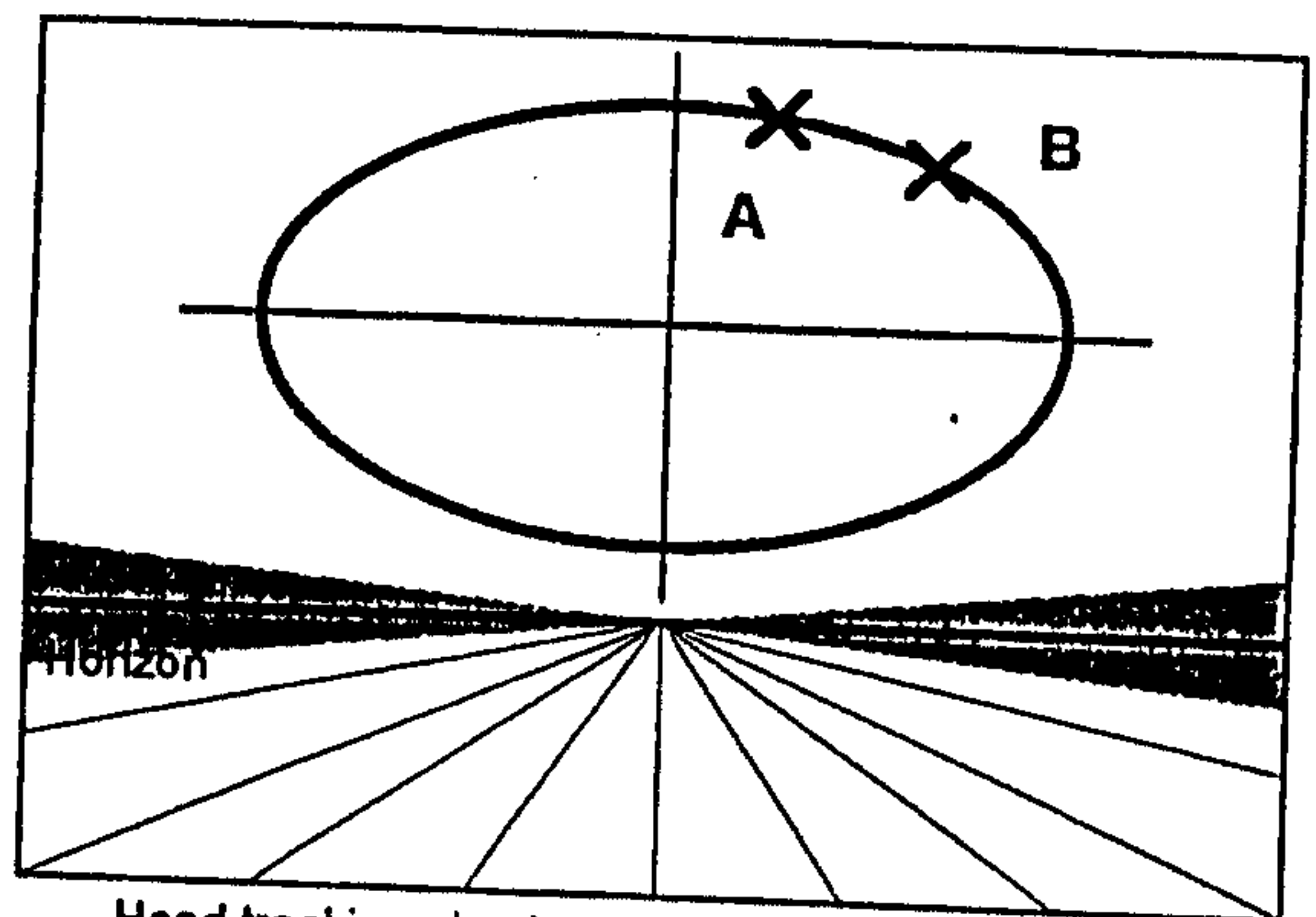
Head flexion and extension without lateral bend

Fig. 12



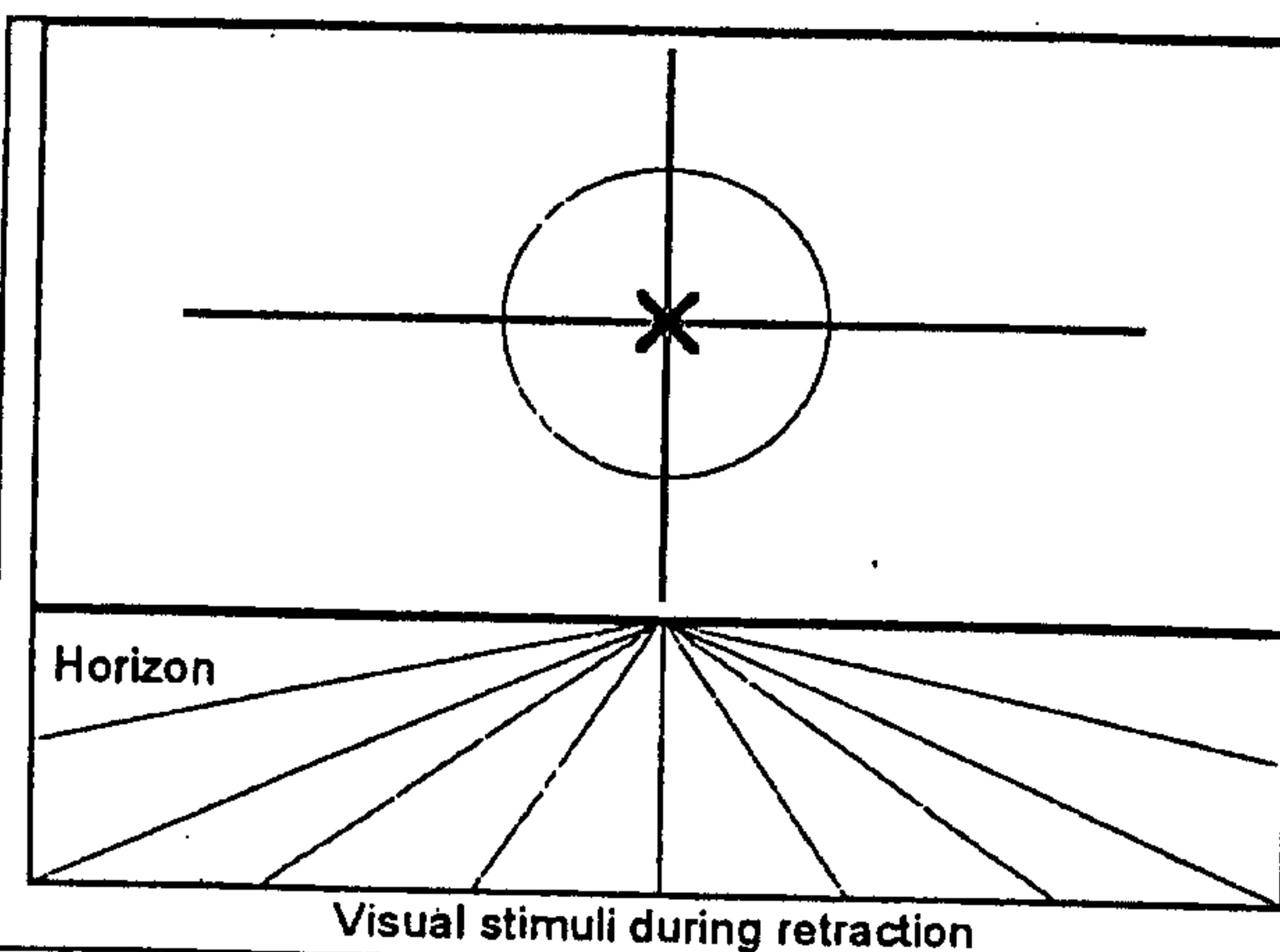
Head tracking diagonal without lateral bend

Fig. 13



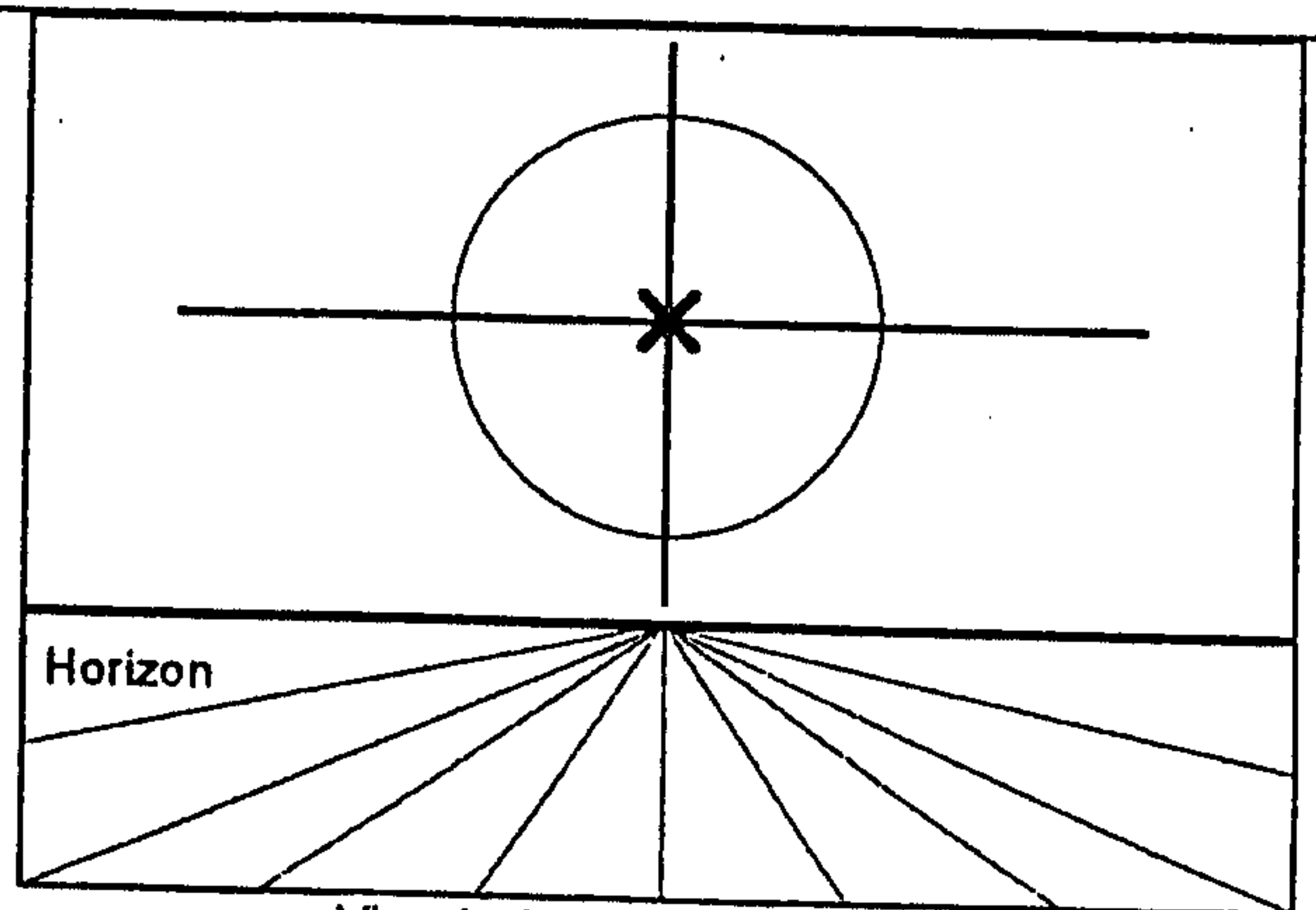
Head tracking circular pattern without lateral bend

Fig. 14



Visual stimuli during retraction

Figure 15 a. The subject retracts his head by a pure translation.



Visual stimuli during protrusion

Figure 15 b. The subject advances his head by a pure translation

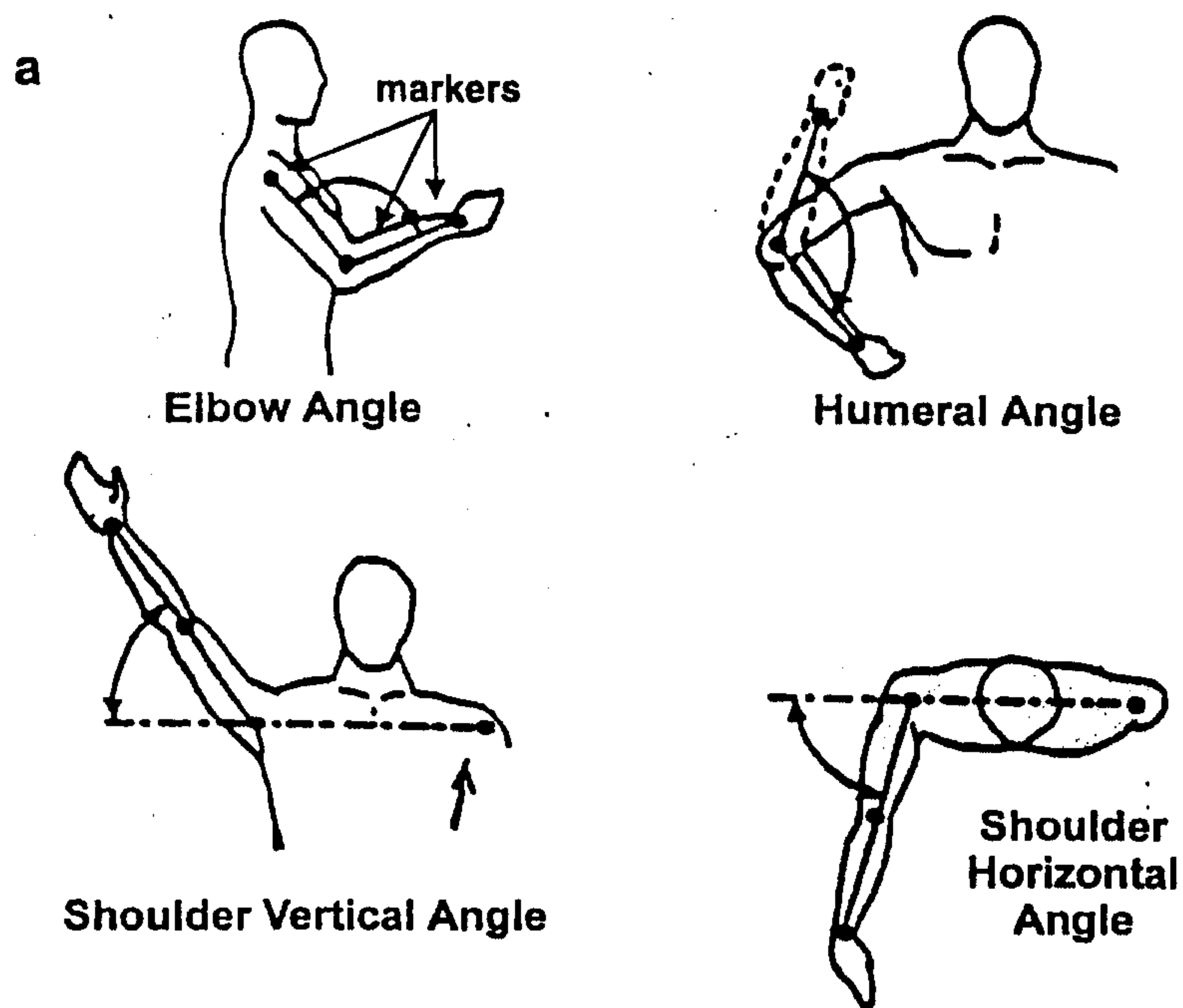


Fig. 16a

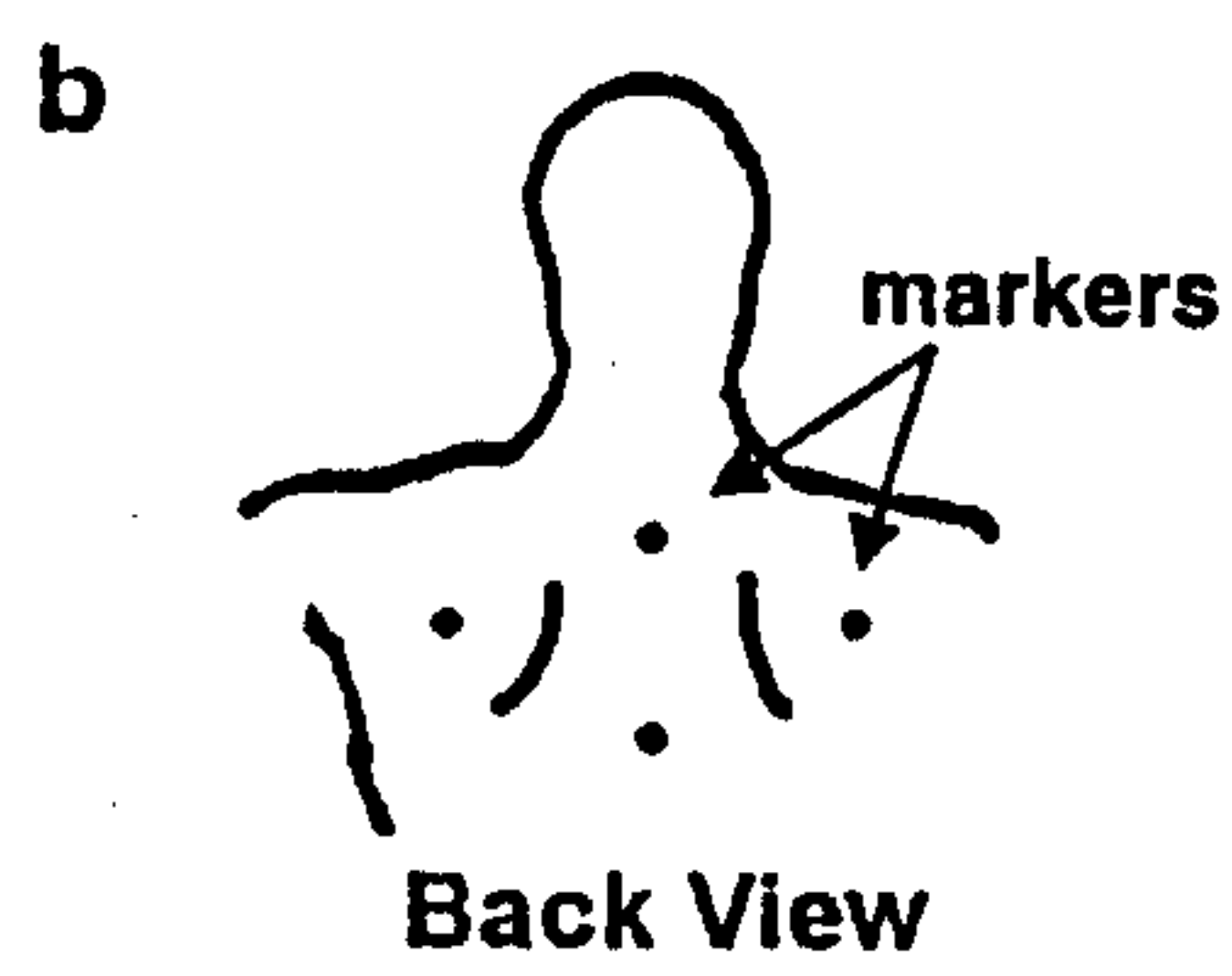


Fig. 16b